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Organizing complex engineering operations throughout the lifecycle: A service-centred view and case studies

Abstract:

Purpose: Strategic trends towards service operations have been widely reported in the recent literature, but organisational capabilities to support such service-centred strategies are less well understood. This paper aims to identify key organisational issues in managing complex engineering service operations throughout the lifecycle.

Design/methodology/approach: Using instruments developed from the product lifecycle management (PLM) technologies and the network configuration concept, key organisational issues for engineering service operations were identified through case studies focusing on complex engineering products and services systems across a variety of industrial sectors.

Findings: The case studies demonstrated different organisational features and strategic priorities of engineering service operations along the whole lifecycle. A generic trend has been observed for engineering systems to move from being design, development and manufacturing focused to embracing support and end-of-life recycling matters.

Originality/value: This paper provides an overall framework for integrating key organisational issues in engineering service operations. It contributes to the service literature by highlighting the need of developing appropriate organisational capabilities to support service-centred strategies with engineering cases. It also provides guidance for companies to manage their engineering network operations throughout the whole lifecycle of complex products and services systems.

Keywords: complex engineering services, engineering service operations, product lifecycle management (PLM), global engineering networks (GEN)

1 Background and Introduction

Strategic trends towards service operations have been discussed in the recent literature focusing on value co-creation (Vargo and Lusch, 2008; Gummesson et al., 2010), goods/products-services integration (Lovelock and Gummesson, 2004; Baines et al., 2009; Shehab and Roy, 2011), customer integration and innovation (Edvardsson et al., 2012; Ettlie and Rosenthal, 2012), and servitization of manufacturing (Neely, 2007; Gabauer et al., 2012). However, the essential organisational capabilities to support and implement such service-centred strategies are poorly understood (Metters and Marucheck, 2007; Karpen et al., 2012) mainly due to the difficulty in defining services and servicing processes (Bretthauer, 2004; Ellram et al., 2004; Chresbrugh and Spohrer, 2006; Baltacioglu et al., 2007), especially in complex engineering operations often consisting of sophisticated network relationships (Gummesson, 2008; Håkansson et al., 2009; Zhang et al., 2011) and associated with unpredictable challenges and risks (Gann and Salter, 2000; Davis et al., 2006; Ng and Nudurupati, 2010). This paper aims to address such knowledge gaps through developing an overall framework for integrating key organisational issues in managing complex engineering products and services systems throughout the lifecycle.

This study began by suggesting a service-centred view of engineering operations to better address the intangible and problem-solving oriented natures of engineering (Hawley, 2003; NAE, 2008; RAEng, 2010). Instruments based on the product lifecycle management (PLM) technologies (Ameri and Dutta, 2005; Grieves, 2006) and the network configuration concept (Boyer et al., 2005; Zhang et al., 2011) were deployed to identify, understand and integrate the key organisational issues in managing complex engineering service operations through case studies across a variety of sectors.

2 Literature Review

2.1 Towards a service-centred view of engineering operations

Services have been considered as the application of specialised competencies through deeds, processes and performance for the benefit of another entity or the entity itself (Vargo and Lusch, 2004). The traditional service marketing literature suggested a set of factors to usefully differentiate services from goods/products on the basis of intangibility, simultaneity, inseparability, perishability, heterogeneity, human-involvement, client-based relationships and customer contact (Pride and Ferrell, 2003; Baltacioglu et al., 2007). More recent studies, however, recommend an integrated view of goods/products and services by focusing on value co-creation, customer involvement and innovation (Lovelock and Gummesson, 2004; Vargo and Lusch, 2008; Ettlie and Rosenthal, 2012).

The traditional engineering management approaches were built on a rather simple assumption of stable environments which were largely product-oriented rather than embracing the intangible, customer-involving and relationship-based features of services (Oliva and Kallenberg, 2003; Vargo and Lusch, 2004; Metters and Marucheck, 2007; Neely, 2009). These product-oriented approaches have been challenged by the dispersion of engineering operations across geography and ownership boundaries (Matos and Fsarmanesh, 2004; Zhang et al., 2008), the need for collaboration with global value networks (Gereffi et al., 2005; Zhang et al., 2011), the progress of digitalisation in engineering operations (Bernus et al., 2003), and an increasing concern for industrial sustainability (Evans et al., 2009). Such challenges are particularly prominent in complex engineering systems which are often based on the effective integration of products and services rather than being product-focused (Gann and Salter, 2000; Baines et al., 2009; Ng and Nudurupati, 2010; Shehab and Roy, 2011).

These complex engineering services systems are generally concerned with developing and exploiting knowledge for innovative design for the convenience and benefit of the customer (Hawley, 2003; Zhang and Gregory, 2011). The working approach seeks for effective problem-solving largely based on engineering knowhow, e.g. engineering expertise or experiences of engineers (NAE, 2008; RAEng, 2010). Recent studies suggested a consistently growing global market of engineering services in the future and an increasing contribution from the less developed countries (Booz, Allen and Hamilton, 2006; Kedia and Lahiri, 2007; Fernandez-Stark et al., 2010). This would lead to radical changes to the traditional product-oriented engineering management methods driven by issues of geographic dispersion, inter-firm collaborations, customer engagement and through-life integration. Table 1 suggests a service-centred view of engineering operations to effectively address the intangible and problem-solving-oriented natures of engineering as well as indicating the linkage to the service literature, especially the traditional distinguishing characteristics of services and the more recently proposed service-dominant logic fundamental premises (Lovelock and Gummensson, 2004; Vargo and Lusch, 2008; Karpen et al., 2012).

(*Insert Table 1 here*- Table 1. A service-centred view of engineering operations)

In brief, a service-centred view of engineering operations is participatory, interactive, dynamic and relational. Engineering servicing processes are focused on deploying intangible skills and capabilities and co-creating value through mutually benefiting relationships (Vargo and Lusch, 2008). The value of service provision will be maximised through an interactive learning process between the service provider and the customer/consumer. Suppliers, customers and other external partners may contribute to the servicing process by co-developing conceptual designs and suggesting application scenarios. At the same time, engineering service providers often work on one-off tasks, and it is therefore difficult to stock a service/solution for future use. Furthermore, human aspects have been a core element in engineering services because of significant people involvement in the process of service production and service provision. To be successful, engineers need to be customer centric - adapting to their often rapidly changing needs whilst collaborating on both solution design and co-delivery. These service related features in engineering operations would require managers to re-think their operations strategies and, more importantly, the organisational matters, with a service-centred view.

2.2 Engineering activities along the product lifecycle

The essence of product lifecycle management (PLM) has been the sharing and management of product data, information and engineering knowledge along a set of stages throughout the physical lifespan of a product or a project (Grieves, 2006; Terzi et al., 2010; Cao and Folan, 2012). The lifecycle stages can be briefly described as beginning-of-life, middle-of-life and end-of-life (Kiritsis et al., 2003), or in more detail as idea generation, defining product, realising, support, service and retirement from a manufacturer’s perspective (Stark, 2006). ISO15288 (2008) suggested a set of lifecycle stages from the conceptualisation of an engineering system to its realisation, utilisation, evaluation and disposal. The development of these stages has been further enhanced by the study of systems engineering (Kossiakoff and Sweet, 2003) and the reference models for engineering design (Ulrich and Eppinger, 2003; Cooper, 2008).

Engineering activities take place at different lifecycle stages (Ameri and Dutta, 2005; Zhang et al., 2007). It should be noted that, despite the rather linear presentation of the above lifecycle models, engineering operations often span different lifecycle stages with iterations or overlaps (Lee et al., 2007; Ibrahim and Paulson, 2008; Zhang and Gregory, 2011). For example, an enhancement or a maintenance project for a long-life and complex product such as an airplane, a submarine, a high-speed train, an offshore oil platform, or a nuclear power station, may include a whole lifecycle of activities from conceptualisation and design to recycling and disposal. Another major challenge to operational processes based on a linear lifecycle model is the shift of core business capabilities from manufacturing to services (IfM and IBM, 2008), as well as the transformation towards more sustainable industrial systems (Evans et al., 2009) and international services outsourcing (Kedia and Lahiri, 2007; Hansen et al., 2013). There is a trend for manufacturers to integrate services into their core product offerings for strategic or sustainability reasons (Oliva and Kallenberg, 2003) while significant revenues can be generated from services. Services can also be a source of sustainable competitive advantage because they are less transparent and hence more sustainable (Desmet et al., 1998; Neely, 2007).

The end-of-life engineering activities, particularly recycling and disposal, have been receiving increasing attention in recent years (Kiritsis et al., 2003; Evans et al., 2009). Companies are encouraged to reuse, remanufacture and recycle end-of-life or returned products in order to reduce their negative impact on the environment (Chung and Wee, 2008). Environmental regulations such as WEEE (Wasted Electrical and Electronic Equipments), for example, transfer the responsibility of collection and treatment of end-of-life products onto original equipment manufacturers (OEMs), and this has led to dramatic changes in their supply chains and engineering networks (Joshi and Dutta, 2007). At the same time, driven by the mounting costs in managing returned products, small companies now seek improved recycling and services processes in order to create new opportunities to undertake sustainable engineering and develop profitable businesses (Min and Ko, 2008). This brings in issues of how small businesses participate in the design and operations of complex engineering networks that are presumably dominated by large OEMs or brand-owners (Environmental Services Association, 2012). Cross-organisation learning has therefore been considered to be an effective strategy for industries to disperse resources and share engineering undertakings collaboratively (Crossan et al., 1999; Prashantham and Birkinshaw, 2008). Recent discussions in this area, such as reverse logistics and sustainable supply chains (Kocabasoglu et al., 2007; Presley et al., 2007; Dey et al., 2011) and waste management (Triantafyllou and Cherrett, 2010; Kuik et al., 2011) for example, have provided useful insights for organising and running complex engineering operations from the perspectives of recycling and disposal.

2.3 Managing the network of complex engineering products and services systems

In brief, complex engineering services systems consist of value co-creation and interaction between engineers (or engineering organisations) specialised in different lifecycle stages of an engineering product/project; and such engineering services systems are often embedded in dynamic networks of relationships across geographical, organisational and functional boundaries (Roy and Potter, 1996; Nellore and Balachandra, 2001; Zhang et al., 2008). These engineering networks demonstrate distinctive features that cannot be interpreted by the traditional functional/divisional organisations or arm's length market mechanisms (Matos and Afsarmanesh, 2004). They are characterised by horizontal patterns of exchanges, interdependent flows of knowledge and resources, and reciprocal lines of communication (Powell, 1990; Koka et al., 2006). In these engineering networks, transactions occur neither through discrete exchanges nor by administrative orders, but through the network of individuals engaged in reciprocal, preferential, and mutually supportive actions (Foss, 1999; Zhang et al., 2007; Håkansson et al., 2009).

A configuration approach has been suggested in the operations management literature to systematically describe the organisational features of a complex industrial organisation (Roy and Potter, 1996; Boyer et al., 2000) or the design, manufacture and support features of a complex engineering system (Burgess et al., 2005). Using a configuration view, organisations function effectively because they put different characteristics together in complementary ways, and hence organisational parameters should be logically configured into internally consistent groupings composed of tight constellations of complementary elements (Mintzberg, 1979; Miller, 1996).

The configuration approach has been widely adopted in complex network operations focusing on different functional areas, e.g. international manufacturing (Shi and Gregory, 1998), research and design (Von Zedtwitz et al., 2004), innovation (Perks and Jeffery, 2006), supply chains (Srai and Gregory, 2008), engineering (Zhang et al., 2007) and solution-based engineering systems (Burgess et al., 2005; Davies et al., 2006). By doing so, researchers are able to simplify and classify complex operations systems and capture their characteristics and capabilities. For complex engineering services operations involving dispersed resources and supporting various tasks throughout the whole lifecycle of engineering products, services and projects, five key organisational areas have been suggested to understand and integrate the operations system's configuration strategy as below (Zhang and Gregory, 2011):

- **Service system structures:** refer to the physical footprint of engineering resources, including the size, number, types/roles of individual service providers/customers, and the rationale for service system design.
- **Operations processes:** refer to the flow of material and information between service providers and customers to provide a valuable service offering, e.g. service design processes, customer relationship management processes, or security and safety management processes.
- **Governance system:** refers to the mechanisms to direct and control the engineering services system, e.g. the authority structure, performance measurement and coordination mechanisms.
- **Support infrastructure:** refers to enablers for service providers to collaborate with each other, e.g. information systems, tools, culture and behaviours.
- **External relationships:** refer to interactions with external partners, e.g. suppliers, customers and users.

An essential purpose of the current research is to extend and further develop these configuration dimensions which were suggested from a manufacturing engineering focused context (Zhang and Gregory, 2011) to address the key challenges and new trends of service centred engineering operations as indicated in Table 1.

2.4 Strategic priorities of engineering services network operations

Operations strategists often construct their observations on a set of competitive priorities (or performance objectives) such as cost, quality, dependability, flexibility, and reliability (Hayes and Wheelwright, 1984; Voss, 1995; Zhang and Gregory, 2013). At the network level, a study by Zhang et al. (2008) revealed strategic priorities of engineering operations from an evolutionary perspective. The study demonstrates that engineering network operations can achieve greater efficiency through economies of scale/scope, international operation synergies, resource sharing, and by reusing existing knowledge and solutions. At the same time, engineering network operation may achieve greater effectiveness through network collaborations. The advantages include a quick response to contextual changes, a quick adoption of market driven or technology driven innovations, a swift allocation of engineering resources, or a constantly (re)shuffled combination of abundant and flexible operation approaches. Zhang et al. (2007) differentiated two types of effective engineering networks by focusing on innovative product development and strategic flexibility. Thus, engineering networks could be configured with strategic priorities for efficiency, innovation and flexibility, which are aligned to the efficiency and effectiveness performance measures suggested by Neely et al. (1995).

To summarise the discussions so far, complex engineering services often involve intensive interactions between the service providers, consumers and customers. Such interactions are characterised as sophisticated combinations of engineering experiences, knowledge and professional skills, which are normally embedded in the technologies, expertise, databases and network relations that an engineering organisation possesses or controls. The development and evolution of such engineering competences are contextually staged within the lifecycle of a complex engineering services system. The engineering organisation therefore will need to configure its main organisational elements strategically in order to be competitive and sustainable in complex engineering networks. The configuration strategy can be characterised in five main organisational areas as shown in Figure 1.

(*Insert Figure 1 here-* Figure 1. Organizing complex engineering services operations)

Although these configuration elements have been suggested mainly from a manufacturing context, they were expected to guide the case studies for capturing and understanding the organisational features of complex engineering services systems. For example, engineering organisations with heavy engineering resources allocated at the manufacturing stage tend to focus on the efficiency of production. Their operations systems are characterised by concentrated engineering resources and they often choose to standardise the process of volume delivery. They tend to practice top-down decision-making and employ centralised governance to co-ordinate dispersed engineering activities; and this efficiency oriented strategic position would favour long-term collaborative partnerships in the provision and sharing of complex engineering services. Another example is engineering services operations focusing on support and maintenance which may have to develop engineering competences of flexibility in order to survive and prosper. The service providers have to customise their service offerings to varying customer requirements. Comparing to manufacturing, engineering services providers have far more direct contacts and interactions with the customers and consumers. This necessitates staff empowerment to make discrete decisions in engineering services operations. Besides the aforementioned efficiency and flexibility orientations, engineering services operations focusing on the beginning(or end)-of-life stage activities, e.g. design & development or recycling & disposal, are expected to have mixed organisational features to achieve other strategic objectives such as innovation and industrial sustainability concerns for example. Such strategic links will be further explored in the case studies.

3 Methodology

The case study method was chosen to empirically enrich and further develop the theoretical elements indicated in the conceptual framework (see Figure 1), and to try to explain these multi-folded and contextualised relationships in a service-centred view (Voss et al., 2002; Stuart et al., 2002). The framework suggests intimate and complex links between different lifecycle stages of engineering service operations and the associated organisational features, which provided an essential guidance at the initial stage of the theoretical development based on case studies. The following main research question was formulated to guide the investigation: How do engineering companies effectively organize their complex services operations throughout the lifecycle? Sub-questions and the key areas of investigation include:

- What are the key organisational features in a company's engineering services operations?
- Why does the company organise its engineering services operations in this way?
- What are the company's strategic priorities in developing and managing complex engineering services systems?
- How are the company's strategic objectives and its organisational features inter-related at different lifecycle stages?

In answering the above questions, an in-depth discussion can then be achieved, which would allow a theory to be enriched and refined (Eisenhardt and Graebner, 2007). A multiple case study approach was adopted because it helped to eliminate potential biases, and produced more robust results to reveal the strategic and other contextual influences on the case companies' engineering network configurations at different lifecycle stages.

3.1 Sampling frame and sampling criteria

The key proposition of this study was that network-based engineering capability is needed for complex service delivery, and an engineering network should be consistently configured across different lifecycle stages to support the focal company's strategic objectives. Therefore, the first sampling criterion is that companies were chosen to 'theoretically fit' (Stuart et al., 2002) within different lifecycle stages. As is indicated in Table 2, eight companies were selected. Studies with cases 1 & 2 were focused on the beginning-of-life engineering design and development activities. Cases 3 & 4 are heavily involved in the middle-of-life manufacturing activities. Cases 5 & 6 provide engineering support and maintenance services as their core businesses. Cases 7 & 8 were chosen because their businesses were in the end-of-life recycling and disposal areas, i.e. they are specialised in the reverse logistics from the collection of end-of-life products to sorting, reusing, reprocessing, refurbishing, and finally land-filling. Considering the exploratory nature of this research and the complexity of the research objective (Meredith, 1998; Voss et al., 2002), a multiple-case design within categories would ideally permit a pattern to be captured and evolve. The pattern-matching logic supported by multiple case studies (Trochim, 1989; Yin, 2009) would allow the researchers to compare empirically based patterns with the predicted ones (or with several alternative predictions). If the patterns coincide, the results can help the case study strengthen its *internal validity* (Voss et al., 2002; Yin, 2009). The 'pattern-matching' approach also allowed us to be flexible in selecting cases from different sectors, focusing on different lifecycle stages, and with different strategic priorities.

(*Insert Table 2 here*- Table 2. An overview of the cases)

Secondly and for a similar reason, the case companies were investigated in detail and are presented here because of their varying business models and strategic priorities, in terms of innovation, flexibility and efficiency (Zhang et al., 2008). Efforts were made to fit two cases into each of the four lifecycle stages. In Yin's (2009) view, analytical generalisation of the findings can be achieved through two types of case selection, which allows *analytical replication* in two ways: literal and theoretical. Literal replication predicts similar results, in contrast to theoretical replication, which produces contrary results but for predictable reasons. Cases 7 & 8, which operated in the reverse logistic process, were therefore treated as a separate category for theoretical replication.

Thirdly, all the selected cases are operating in engineering-intensive sectors such as aerospace, defence, mechanics and electrics, computers and electrics, in which engineering functions play a key role in the business. All companies participated in this research acknowledged or reported that they have significant engineering activities in their business operation. For example, Case 3 reported a manufacturing process with about one-third of engineering-intensive activities. Case 5 went even further by claiming that about 75% of their maintenance and repairing projects are engineering-based activities. Focusing on engineering-intensive business allowed those *informative cases* to be selected (Swanborn, 2010). The case study interviewees and workshop participants had worked with engineering-intensive processes - or units - such as engineering consultancies, hardware or software developments, technology support departments, (physical and technological) systems monitoring, on-site services and engineering-intensive projects. The workforce had in common a background of engineering by education and/or by profession. This authentic representation of engineering environment by both the participants and their participating organisations would therefore ensure and enhance credibility and transferability in the qualitative research, as proposed by Lincoln and Guba (1985). This allows a sensible comparison across the cases as well as the application of findings within each of the subgroups of the cases.

Finally, all cases selected operated on different scales in terms of volume and variety (Johnston and Clark, 2008). The very much exploratory nature of this study necessitated considering these latent elements that were otherwise affecting the catch-up and measurement of organisational features and the clustering of the companies in their strategic priorities. The selection of participating companies enabled a sensible analytical induction to be adopted later in the stage of data analysis (Johnson, 1998). Collectively, the case study companies demonstrated a comprehensive view of engineering operations in a variety of contextual situations (see Table 2), for example, from different sectors and with varying size. As argued by Stuart et al. (2002) and Johnson (1998), to analytically generalise from individual, and noticeably deviant, cases to a broader theory will help to enhance the *external validity*. All the case companies are based in the UK.

3.2 Data collection and data analysis

The sampling process started with two industrial workshops, which about two dozen companies attended. The workshops were held for the participating companies to share their views over the trend of engineering network operations and respective practices in developing engineering capabilities throughout the lifecycle. Willingness to further participate in this research was initially sought from the workshop attendants. This was followed by contacting the potential participants via the telephone and by company visits. On average, companies selected for the case study were each visited twice, and four interviews were taken on site or via the telephone. During this time, additional companies such as cases 7 and 8 were spotted and introduced to the project. Some companies who initially participated in the workshop withdrew because of timetabling, security and safety reasons, or sampling frame requirements. This mutual selection took place in parallel with data collection and data reduction using template analysis (Miles and Huberman, 1994).

The data collection process featured multiple approaches that were adopted in this research including documentary studies, company visits, interviews and workshops. The collection of different kinds of complementary data about the theory under investigation allowed the researchers to overcome the bias inherent in the single-mannered approach, i.e. a *methodological triangulation* (Smith, 1975; Gill and Johnson, 2010), which was justified in the case study design. All of the participating companies had comprehensive websites for public access as well as business development. Internet exploration and company presentations provided the researchers with an overview about the case study companies. An in-depth comprehension was further achieved through studying the companies' internal documents such as engineering strategies, engineering operational framework, guidelines for overseas engineering staff, handbook for international projects and the concept of operations. Semi-structured interviews were designed to take into account the interviewees' contextual situations. The interviews aimed to identify key issues in the design and operations of global engineering networks. Senior managers such as business group directors, global/regional engineering directors, business excellence directors, or engineering capability managers, were interviewed in at least two rounds in each case.

The first round interviews were exploratory and the second round was conducted to clarify issues and events and to verify preliminary conclusions that were drawn upon within each case and through cross-case analysis (Yin, 2009; Voss et al., 2002). Workshops were organised as a mechanism to explore emerging topics and spot new issues, and at the same time to verify and test research findings. For example, recycling and disposal focused engineering operations were identified as an area of poor performance but increasing importance in one workshop, and the participants suggested potential cases to facilitate further exploration in relevant areas. A set of tools (such as protocols, instruments, and worksheets) was used to inform the development of the preliminary conceptual framework (see Figure 1), and then used to clarify and verify these previous findings with a view to keeping an *audit trail* of the reported research (Gill and Johnson, 2011).

4 Case Studies

Table 3 presents an overview of the key case study observations that contributed to an in-depth understanding of the organisational features of complex engineering service operations at different lifecycle stages: design & development, manufacturing, support & maintenance, and recycling & disposal.

(*Insert Table 3 here*- Table 3. An overview of the key case study observations)

4.1 Design & Development

Engineering services operations in cases 1 and 2 have been focused mainly on design and development related activities. Such operations often give high priority to innovation related performance objectives. Organisational features of the cases are in the middle of the spectrum (see Figure 1). On one hand, these engineering systems need to be close to leading technology bases or customer bases in order to develop innovative solutions. On the other hand, these systems need a critical mass to develop and maintain leading technologies or expertise in core capability areas. Their engineering services operations require freedom for creativity and diversity as well as some level of standardisation to guide their largely unpredictable innovation activities. For example, Case 1 is the high voltage transformer operations of a global leading engineering company in power and automation technologies. The case company has two group research laboratories dedicated to power technologies and automation technologies respectively. Each laboratory collaborates with universities and other external partners to support its divisions in developing cross-divisional technology platforms. The company also has engineering resources dispersed into local markets for three main reasons. Firstly, high voltage transformers are heavy and big and therefore are difficult to be shipped around the world. Secondly, its engineers have to respond to customer requirements quickly in order to avoid disastrous consequences. Thirdly, its operations have to meet local government legislations and many other local market requirements. These engineering resources are embedded in numerous independent profit centres in over 100 countries. Internal market mechanisms are adopted for resources' allocation between profit centres. Each engineering centre can make its own decisions on what activities to undertake. It will charge other business units and external customers at approximately market prices. The company has developed an information and communication technologies (ICT)-enabled engineering platform to support collaborative processes for its widely dispersed engineering groups. All the business partners (i.e. producers, suppliers and customers) can be involved in the company's product development processes at the earliest opportunity. Early integration of expert knowledge (usually dispersed around the globe) can considerably reduce development time, while spontaneous, ad-hoc collaboration between team members drives innovative solutions that not only improve product design but also minimise the number of design changes.

4.2 Engineering Manufacturing

Engineering services operations in cases 3 and 4 have been focused on manufacturing related activities. Such operations tend to give high priority to efficiency related performance objectives. Organisational features of these cases share some common patterns, e.g. concentrated resources, standardised operations processes, global support infrastructure, and centralised governance with well-defined performance measures. These engineering systems have also developed strategic partnerships with suppliers to improve the leanness of the whole supply chain. For example, Case 3, regional operations of a leading global business group in military land systems, provides complex military weapons and vehicle systems for the local army. It employs over 3,800 people at a few major sites mainly focusing on production and delivery activities, reflected by the number of engineers involved and perceived core capabilities by customers and competitors. The case company has launched a series of initiatives since the beginning of this century to improve the efficiency of its engineering operations, e.g. focusing on specialised core expertise or capabilities, consolidating resources to a few major engineering centres, and the implementation of lean engineering. Its engineers often work closely with customers through joint project teams, which enables the development of innovative solutions to satisfy customer needs in the current situation and in the future, and at the same time allows the company to identify novel ways of cost reduction through collaboration with customers. Engineering activities for product design and development emphasise efficiency and innovation at the same time. Service and support activities pay more attention to flexibility. Disposal and recycling activities have to follow the existing regulations or agreements, which have not been considered as a major contribution to the business. Since the middle of this decade, a restructuring programme has transformed the company's engineering network from being site focused to being capability focused in order to improve programme performance and operational efficiency. The transformation has focused on developing a critical mass of engineering resources in each technical domain with the aim of bringing a uniform, high standard of performance to the whole business. Core engineering areas have been identified and the major sites will focus on different core areas. Common processes have been developed with an integrated business management system driving common practice throughout the network. All engineering centres are required to measure their performance regularly against a set of common metrics, e.g. resource, financial, training, processes, information systems, facilities, or suppliers/partners. A central resource planning system has been established to forecast the current and future engineering load accurately and reliably. In addition, common cross-site toolsets have been deployed to create a virtual environment that will allow engineers to work on a single programme from multiple sites without degrading performance.

4.3 Support & Maintenance

Engineering services operations in cases 5 and 6 have been focused on support, maintenance and decommissioning related activities. Such operations tend to give high priority to flexibility related performance objectives. Common organisational features of these engineering systems include dispersed resources with customers and capability centres, tailored processes for customer needs, local support infrastructure, and decentralised governance based on local decision making. These engineering networks have also developed a strategic partnership with customers to improve the responsiveness of the whole supply chain. For example, Case 5 is a global first tier supplier of aerospace engineering services. Its engineering resources are highly distributed with customer bases, technology bases, and manufacturing facilities around the world. The company has a set of independent centres of excellence which are responsible for local businesses, with the central corporate function reviewing their performance quarterly and the technology committee overseeing the long-term capability development. These centres are strategically located around the world and can continuously operate from different time zones over 24 hours. Supported by a powerful Internet-based global information management system, engineers can easily switch between projects even without physical relocation. In order to cope with uncertain customer demands, the company has developed a full range of flexible, adaptable and pro-active operating approaches for different kinds of customers' requirements, e.g. on-site working, package work, integrated solutions, design and build, strategic relationships, dedicated and collocated teams, joint teams, or partnerships. These approaches are customer oriented and can be used on an integrated or standalone basis. The company has also developed an efficient process to restructure its engineering network by acquiring external resources and integrating them into its global network. Acquired engineering centres, which usually possess unique technologies or skills, will join the company's engineering network as new centres of excellence after re-organising (or relocating) their resources and connecting them into the company-wide information system. The new centres operate autonomously, with their expertise accessible to the other centres via the central engineering information system.

4.4 Recycling & Disposal

Engineering services operations in cases 7 and 8 have been focused on recycling and disposal related activities. Case 7 is a social enterprise and charity, which has been operating successfully since 1995. It is recognised nationally and internationally as an example of how the voluntary, public and commercial sectors can work together for the benefit of all parties and for the good of environment and community. The business model is to reuse and recycle end-of-life electronic products rather than sending them to landfill. The company recruit from the 'intermediate labour market' (e.g. disadvantage adults) and provide engineering training programmes for local businesses and retailers. Case 8 is specialised in providing comprehensive recycling services to the producers, distributors and users of computers and communication systems. Established in 2007, the company has committed to divert as much electronics waste as possible away from land-filling through convenient and rewarding collection and reprocessing methods and sustainable reuse of electronics that may otherwise be deemed 'waste'. The company provides professional consultancy and compliance services to these clients in their implementation of the EU Waste Electrical and Electronic Equipment Directive (WEEE). It has developed partnership with network operators, which allows the company to take back and process a huge volume of devices. It has also registered with environmental agencies and regularly report to them on waste management matters.

Observations in cases 7 & 8 suggested that engineering services operations focusing on recycling and disposal tend to fulfil local economic, societal and environmental responsibilities as a key performance priority. Case 7, for example, formed strategic partnerships with the local city councils, national retailing companies and international manufacturers. These long-term multilateral relationships allowed the company to contribute to local employment and skill development as well as to the welfare of low-income families. Engineering expertise was widely applied and constantly upgraded in delivering training and consultancy programmes such as waste management, in monitoring test and refurbishment for used or discarded products, and in taking-back, sorting, exporting and recycling activities. The case companies networked, by contracting or regular meeting, with external partners to change ‘waste management’ into ‘recourses management’. Possessing and sharing a variety of technological and engineering expertise became crucial in sustaining business and service operations. In brief, cases 7 & 8 worked with end-of-product users, local communities and governments, manufacturers and distributors to form a collaborative network of engineering service operations. It apparently helped to feedback to manufacturers and other key players in their sustainability considerations throughout the entire product lifecycle, including the extraction and treatment of raw materials, manufacturing, distribution, use, re-use, recycling and disposal.

4.5 Reflection on the Key Configuration Dimensions

Zhang and Gregory (2011) suggested a scaling method to possibly compare the organisational features of the case companies and effectively indicate their relations to the primary value creation mechanisms. We noticed some major difficulties to apply the method in the current research. For example, the network structure of service operations is generally much more dispersed than the cases reported in Zhang and Gregory (2011) because of the actual requirements for service provision to be close to customers and users (structures: concentrated-dispersed). At the same time, customers and suppliers are often more closely involved in service delivery, and service operations processes therefore need to accommodate such engagement and interactions (processes: standardised-customised). Furthermore, more close relationships between services providers, suppliers and customers are required for effective value co-creation (relationships: collaborative-transactional). Differences in such important areas would significantly hinder the utility and usefulness of the scaling method used by Zhang and Gregory (2011) - most of the cases may eventually turn up at the same end of a spectrum. Nevertheless, this could be positively seen as a research opportunity to update and further develop the scaling method for service operations. For example, we have been suggested to update the scaling method by using 'global operations' and 'local operations' to differentiate the network structure of service operations.

5 Discussions

The cases demonstrate different organisational features within each of the 'theoretical sets' as well as across them (see Table 3). This suggests a natural strategic difference between product-oriented engineering operations and service-oriented engineering operations. For product-oriented engineering operations, an integrated engineering network configuration often has a strong performance implication for efficiency, and a dispersed engineering network configuration often has a strong performance implication for flexibility. Service-oriented engineering operations have fundamentally different requirements in the aspects of intangibility, customer-involvement, and external relationships. The network structure tends to be dispersed with customers, the operations processes, governance system, and support infrastructure are often tailored for customer needs, and the relationships with customers and users are particular important to the business. Introducing a service-centred view of engineering operations has been useful in the case companies to understand different types of engineering activities, interactions between different lifecycle stages and the organisational requirements.

A generic trend has been observed for engineering systems to move from being design, development and manufacturing focused (e.g. cases 1-4) to embracing support and maintenance and the end-of-life matters (e.g. cases 5-8) (Davies et al., 2006; Neely, 2009; Neely et al., 2011). Companies such as Cases 1, 4 and 5 extended their product offerings into services that enabled them to move up/down the engineering value chain (Zhang et al., 2011) to find new business opportunities. Companies such as Cases 2 and 6 bundled their products with services to involve closer coupling and integration with the customer. They developed embedded technologies in their products, which enabled their engineers to track the health and remotely diagnose the use of the products. This allowed companies to arrange for effective repairs and maintenance. Their engineering networks were heavily reliant on the key manufacturers to provide technical capabilities for new market development, social capital development, and for exploitation of their technical capabilities in service provision. As indicated in Cases 7 and 8, in addition to the normal economic concerns, environmental and societal issues have been concerned in engineering services operations for the end-of-life recycling and disposal businesses.

It has been noticed that none of the case companies spread their engineering services operations substantially across all the lifecycle stages. Although there is an increasing amount of literature addressing environmental issues and sustainability concerns (Guide, 2000; Gao and Zhang, 2006; DEFRA, 2007; Srivastava, 2008; Lau and Wang, 2009), most of the case companies showed a relatively low operations priority for disposal and recycling related engineering activities. A potential reason could be a lack of engineering organisations mobilising their engineering expertise and resources on disposal and recycling activities. The volume of the used products and the cost of collecting them may not justify a dispersed engineering network from an economic perspective. Alternatively, the case companies expressed a variety of impact considerations of the end-of-life matters, including the extraction and treatment of raw materials, manufacturing, distribution, use, re-use, recycling and final disposal. The decommissioning and disposal activities have actually been organised by the owner of the products in some cases in the aerospace industry (e.g. Cases 5 and 6). Manufacturers have been in the position to support these end users in decommissioning high value, complex products and systems. However, it may be in the end users' best interest and best knowledge for manufacturers to not take charge of recycling and disposal, as suggested in some of the case studies (e.g. Cases 3 and 5). This has posed a challenge regarding how to effectively mobilise and allocate engineering expertise and resources across organisations from different sectors and locations in terms of coordination and inter-project learning and inter-organisational learning (Davies et al., 2006; Jones and Macpherson, 2006).

Cases 7 and 8 particularly reveal that there exists a strategic intention of building network-based engineering capabilities involving external partners. The third party companies, which are often small and locally based, contribute to the completion of PLM by providing engineering capabilities alongside the reverse logistics (Dey et al., 2011). Such observations shed light on the development of the preliminary conceptual framework by addressing environmental and societal issues. In other words, a global engineering network is empirically practised in a wider sense not merely to focus on global and economic concerns, but also to address local and sustainable needs. Collaborative networks of small companies provide an irreplaceable and pragmatic mechanism in closing the loop of PLM, through effective inter-organisational learning and localised networking among service providers, manufacturers and brand owners (Paulraj et al., 2008; Prashantham and Birkinshaw, 2008).

This in turn will improve our understanding of engineering network operations by emphasising the role of third party companies (Min and Ko, 2008; Lau and Wang, 2009) and reverse logistics management (Krumwiede and Sheub, 2002; Srivastava, 2008).

6 Conclusions

This paper intends to improve the current understanding on how complex engineering services systems are organised and managed locally and globally. Based on the existing literature, this paper suggests an integrating framework for strategically organising engineering activities and expertise throughout the lifecycle. The framework has been expanded and enriched with a series of carefully selected case studies focusing on complex engineering service operations.

This paper suggests that companies would prioritise the performance objectives of their engineering service operations differently at different lifecycle stages. Engineering services focusing on the early lifecycle stages usually give higher priority to innovation related performance areas; those in the middle of the lifecycle often give higher priority to efficiency related performance areas; whilst those at the later lifecycle stages tend to give higher priority to flexibility related performance areas. In addition, environmental and societal issues are increasingly concerned in end-of-life recycling and disposal focused engineering activities.

The case study observations suggested appropriate organisational features to support these different strategic priorities. Engineering services systems which are operated for higher efficiency are often characterised by concentrated engineering resources, standardised operations processes, centralised governance, global support infrastructure, and strategic supply chain management focusing on leanness. Those run for greater flexibility are often characterised by having dispersed engineering resources with customers or capability centres, adaptable operations processes for customer needs, decentralised governance, local support infrastructure, and strategic supply chain management focusing on responsiveness. Those run for greater innovation ability need to balance the operations requirements for creativity and reliability simultaneously. Their organisational features are often in the middle of the configuration spectrum from an integrated engineering system to an autonomous federation.

This paper bridges two main bodies of knowledge focusing on engineering network operations and complex services systems. It enriches the service literature by demonstrating appropriate organisational capabilities to support services focused strategies and extends the theoretical understanding of global network operations with a service-centred view. This provides a stepping-stone for developing an overall strategy for integrated manufacturing and servicing operations, and thus will help managers to optimise their current engineering systems or to design new engineering systems to deliver through-life engineering capabilities around complex products, services and projects.

This research has a number of limitations. The first one concerns the unit of analysis. Some the chosen cases represent engineering capability at the company level. Many others are the local or regional engineering services operations of a large global company. With hindsight it is suggested that the configuration of engineering capability might be better studied by taking a company's strategic business centres as the unit of analysis. Alternatively, an in-depth case study is recommended to capture the varying engineering networks within one company covering all the lifecycle stages.

A second limitation lies in the data collection process. This research involved managers from different parts of the businesses studied, in order to gain a comprehensive view of engineering operations at different lifecycle stages. It was difficult to include managers of the same seniority or with similar levels of knowledge about their businesses. Opinions and accounts from senior managers and experienced engineers may have significant influence on a company's decision making processes and thus be very useful to the research outcomes. This may affect the drawing of a fair conclusion. An example was that most managers interviewed in Cases 1-6 have indicated little dedicated responsibility for waste management.

A third limitation is in relation to the generalisability of the research findings. Some findings perhaps cannot be automatically applied to engineering service operations in all different contextual circumstances. This should not be considered as a major flaw in the research design because of the theory building and exploratory nature of the current study. However, it will be useful to develop a large scale survey based on the framework that has been informed in this study.

This paper suggests three directions for future research. The first one is to capture generic engineering organisation patterns through a larger scale empirical investigation of a broader range of complex engineering products, services and projects. The second one is to investigate performance priority trade-offs between different lifecycle stages. Last but not least, it will be interesting to explore the performance implications of societal and environmental issues in providing sustainable engineering capabilities around complex products and services systems.

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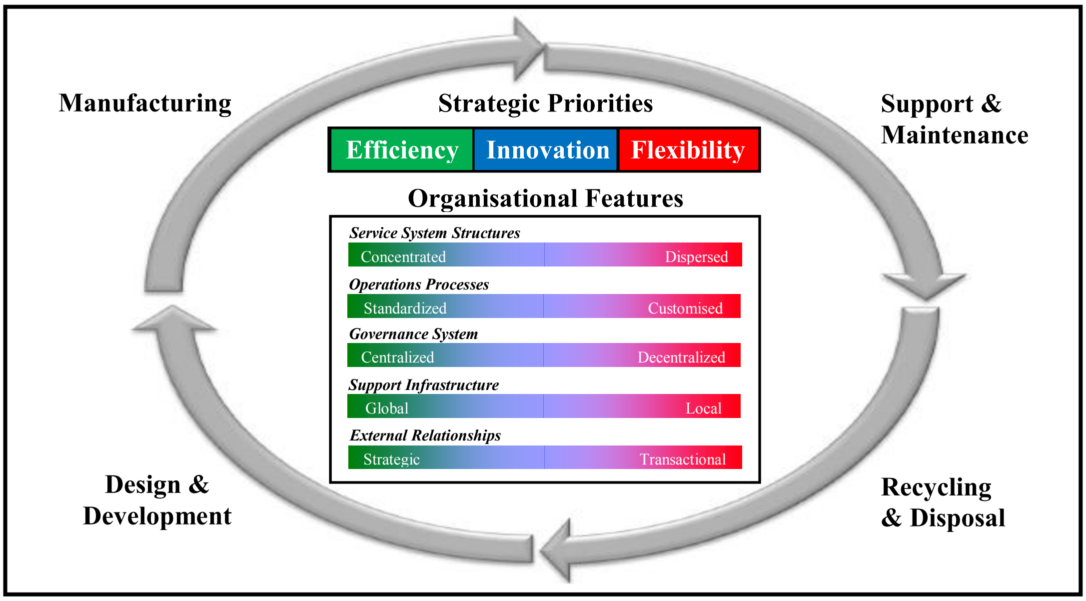

Figure 1. Organizing complex engineering services operations

Table 1. A service-centred view of engineering operations

Service-centred view of engineering operations	Product-centred view of engineering operations	Linkage to the service literature
• engineering working approach is heavily reliant on intangible knowledge of engineers • engineering outputs are a subjective and user-dependent solution or design • variable processes and outputs; output based 'service level agreements'	• engineering manufacturing is largely reliant on equipments' and operations' instructions • engineering products are measurable and pre-specified • standardised processes and outputs; well defined product specifications	Intangibility; heterogeneity; knowledge based value creation
• value is perceived and partly co-determined with the customer • customers are involved in the value creation process • unable to store engineering solutions but it is possible to develop engineering capabilities	• value is determined by the producer, i.e. the engineering organisation • customers are often separate from the production process • it is possible to store outputs, e.g. the application of engineering design	Inseparability of production and consumption; customer involvement and value co-creation
• engineering working approach requires collaboration with a wide range of partners • with high impact of human aspects and being customer centric • engineering organisations can only make value propositions and co-create value with their customers	• engineering products may require transaction based relations with customers and suppliers • with relatively low impact of human aspect and low customer centric • engineering organisations can deliver or transfer value to their customers via products	Customer oriented and relational; value-co-creation; networks of interaction and relationships

Table 2. An overview of the cases

Cases & sectors	Types of engineering service operations	Focusing lifecycle stages
Case 1 Electronics	The high voltage transformer operations of a global leading engineering company in power and automation technologies, employing 15k people in over 100 countries, revenue US$4.5 billion in 2008	5 interviews focusing on beginning-of-life engineering design and development operations
Case 2 Defence	Regional operations of a international defence company, employing 3k people in a few major sites and customer bases, revenue $560 million in 200	4 interviews focusing on beginning-of-life engineering design and development operations
Case 3 Defence	A global leader in military land systems with sales of $7.1 billion in 2007	6 interviews focusing on middle-of-life engineering manufacturing operations
Case 4 Energy	The exploration and production operations of a global energy company, employing 20k people in over 100 countries, revenue £9.1 billion in 2008	4 interviews focusing on middle-of-life engineering manufacturing operations
Case 5 Aerospace	The aerospace operations of an international engineering group, employing 6k people internationally, revenue $820 million in 2007	5 interviews focusing on middle-of-life engineering support and maintenance operations
Case 6 Aerospace	The service operations of an engine manufacture, revenue £4.3 billion in 2007	4 interviews focusing on middle-of-life engineering support and maintenance operations
Case 7 Mecha-trics	Local charity and social enterprise, employing 90 people with revenue of £2 million in 2008	3 interviews focusing on end-of-life disposal and recycling operations
Case 8 ICT	Regional operations of national ICT recycling company, employing 65 engineers with annual revenue of £8 million in 2008	3 interviews focusing on end-of-life disposal and recycling operations

Table 3. An overview of the key case study observations

Cases		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Focusing lifecycle stages, and strategic orientations for engineering services operations		**Design and development, focused on innovation**		**Engineering manufacturing, focusing on efficiency**		**Support and maintenance, focusing on flexibility**		**Recycling and disposal, focusing on industrial sustainability issues**	
Organisational Features	**Service System Structures**	Global labs and local engineering centres	Regional engineering centres	Corporate engineering centres	Central engineering and local project teams	Local engineering centres	Local engineering centres	Local engineering centres supported by the national centre	Local engineering centres
	Operations Processes	Common processes for key activities	Regional common processes	Common processes for key activities	Common standards from the project academy	Common processes tailored for local needs	Few key processes for reference	Common process tailored to local needs	Common processes tailored to local needs
	Governance System	Business unit level control with central influence	Regional control	Business group level control with central influence	Tight control with central engineering oversight at each key stage	Local control with central influence	Local control	Local control	Local control
	Support Infrastructure	Common systems within business groups	Common basic systems	Common basic support systems	Common engineering tools and single data management system	Customised support systems	Local support	Local support	Local support
	External Relationships	Local or regional partnerships with suppliers	Regional relationship with customers and suppliers	Strategic customer / supplier relationship on key activities	Significant use of external partners with in-house expertise to oversee projects	Strategic partnership with key customers	Local partnership with customers	Partnership with OEMs local councils, & suppliers	Strategic partnership with OEMs, retailers, & local councils